

Coatings for Oxidation and Hot Corrosion Protection of Disk Alloys

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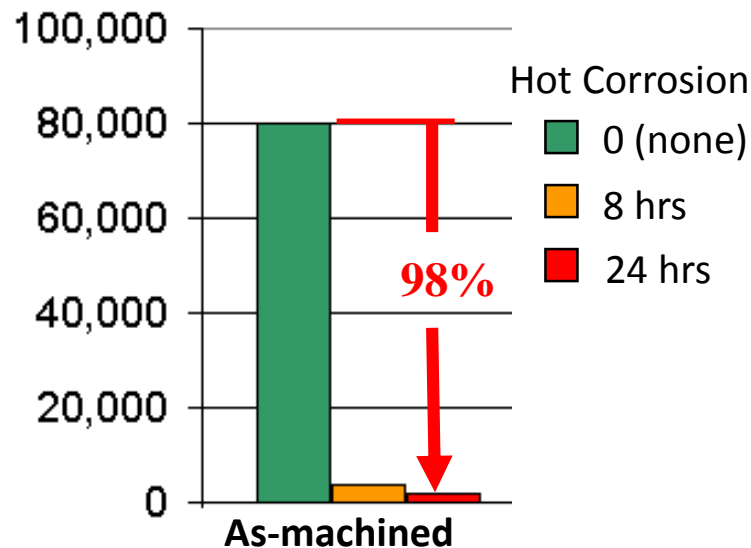
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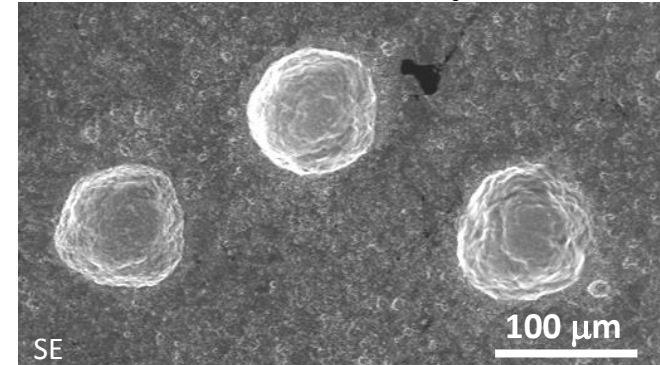
The need for corrosion protection of superalloy disks

Fatigue Life at 704°C (1300°F)
Uncoated ME3 Fatigue bars

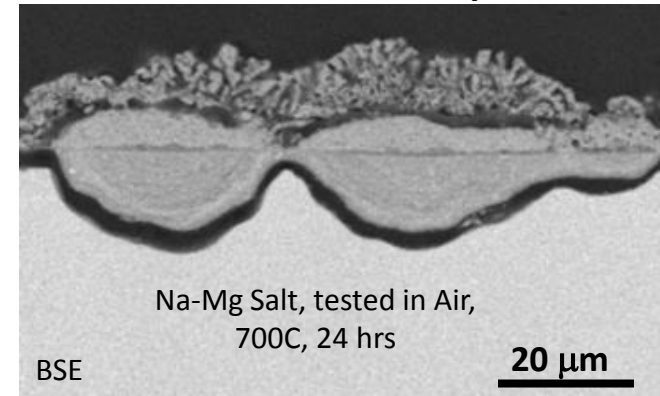


Ref: T. P. Gabb, J. Telesman, B. Hazel, D. P. Mourer, "The Effects of Hot Corrosion Pits on the Fatigue Resistance of a Disk Superalloy," *JMEP*, V. 19, 77, 2010.

Surface view of pits



Cross-section of pits



Hot corrosion associated with pitting can severely reduce fatigue life of disk superalloys

Purpose:

Develop coatings to mitigate oxidation and hot corrosion attack in order to maximize low cycle fatigue (LCF) life of coated disk alloys

Approach:

Evaluate effect of various coating factors on LCF life

Coating chemistry, deposition process, coating thickness, etc.

Surface treatments:

- Pre-coat (polish, grit blast, wet blast, shot peening)
- Post-coat (shot peening, Low PO₂ diffusion anneal)

Evaluate effect of coatings on LCF life

- Coated versus uncoated
- With and without oxidation (OX) and hot corrosion (HC) exposures

Experimental Procedures

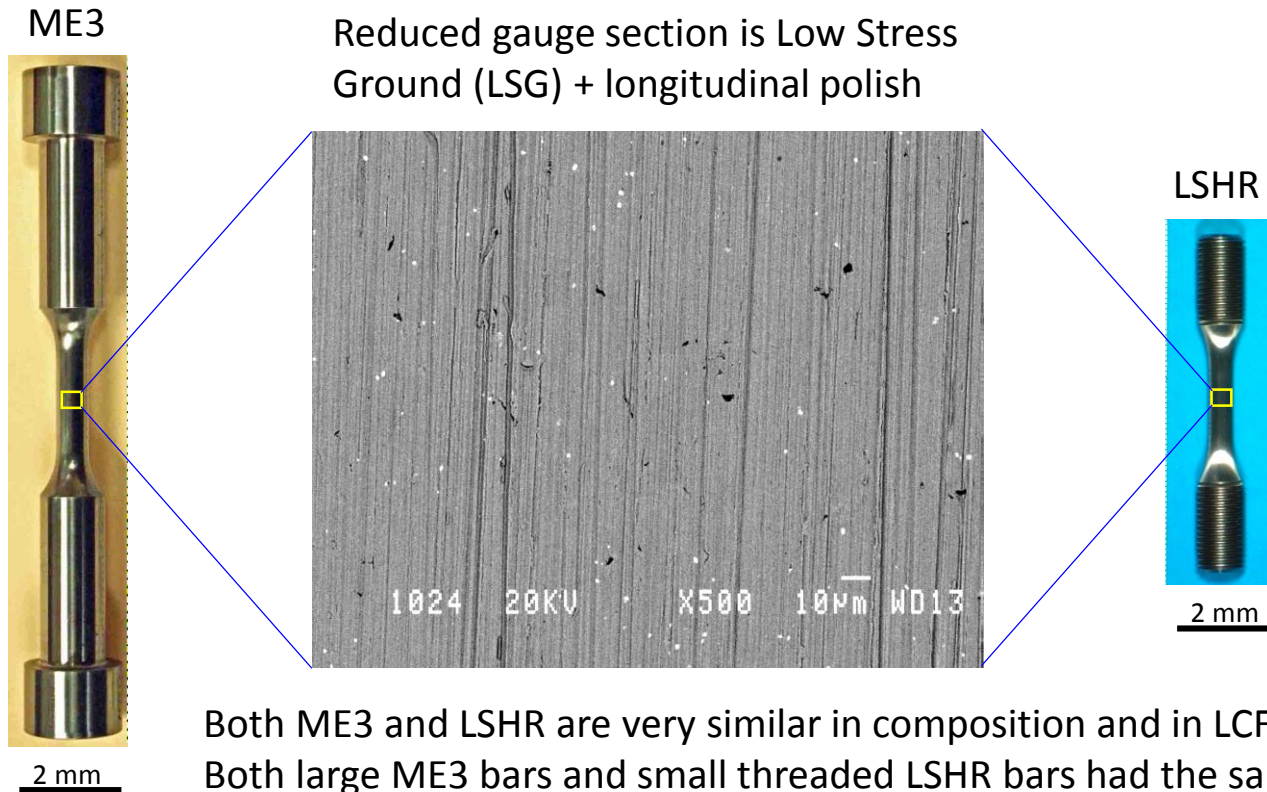
1. As-coated with low PO_2 diffusion anneal
 - A. Coat LCF bars with Ni-Cr coatings
 - B. Low PO_2 diffusion anneal (8 hrs, 760°C , PO_2 of 10^{-17} atm O_2)
 - Diffusion bonds coating and substrate and promotes protective Cr_2O_3 formation
 - C. Evaluate LCF life (760°C , 1400°F)
2. Evaluate effect of shot peening
 - A. As-coated LCF bars
 - B. Shot peen coated surface (16N-200%)
 - C. Low PO_2 diffusion anneal
 - D. Evaluate LCF life
3. Evaluate effect of environmental exposures
 - A. As-coated LCF bars + shot peen + low PO_2 diffusion anneal
 - B. Oxidation exposure (500 hrs, 760°C (1400°F) in air)
 - C. Hot corrosion exposure (2 mg/cm² 72% Na_2SO_4 -28% MgSO_4 salt, 50 hrs, 760°C (1400°F) in static air), sonic water clean
 - D. Evaluate LCF life

Two similar disk alloys were tested

- LSHR (Low Solvus, High Refractory) (W+Nb+Mo+Ta=10.1 wt.%)
- ME3 (W+Nb+Mo+Ta=9.0 wt.%)

Weight Percent

	Ni	Co	Cr	Al	Ti	W	Nb	Mo	Ta	Zr	B	C
LSHR	50.14	20.4	12.3	3.49	3.48	4.24	1.51	2.72	1.59	0.05	0.03	0.05
ME3	50.48	20.6	13.0	3.23	3.59	1.97	0.89	3.73	2.38	0.05	0.02	0.06



Both ME3 and LSHR are very similar in composition and in LCF life. Both large ME3 bars and small threaded LSHR bars had the same polish in the reduced gauge section.

Experimental Procedures

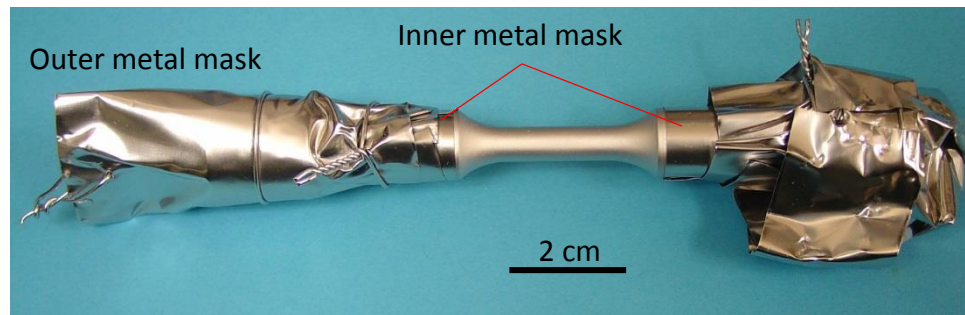
Three Ni-Cr-Y Coatings (Low Cr, Med Cr, High Cr)

Coating Designation	Target 1 (wt.%)	Target 2 (wt.%)	Coating Thickness* (um)	Deposited Coating Composition** (wt.% Cr)
Low Cr	Ni-27.3Cr-0.12Y ¹	-	20.4 ± 0.6	29.1
Med Cr	Ni-27.3Cr-0.12Y	100% Cr	21.5 ± 0.9	37.0
High Cr	Ni-27.3Cr-0.12Y	100% Cr	19.8 ± 1.9	44.4

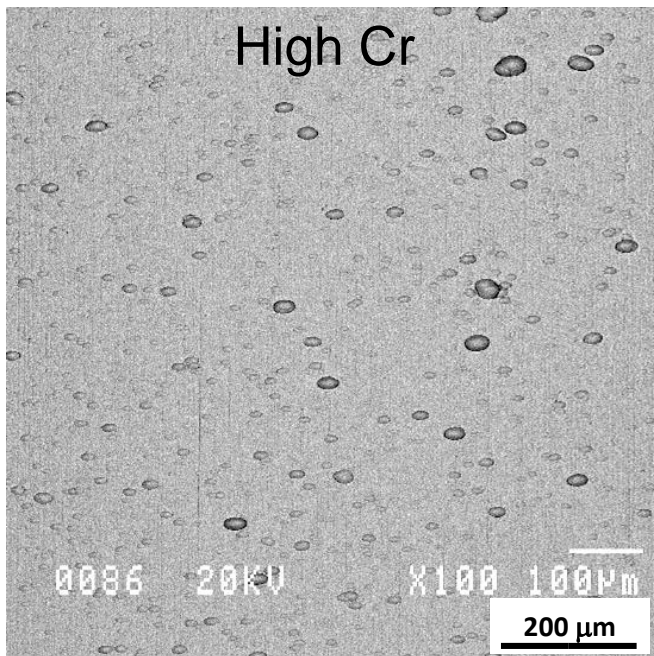
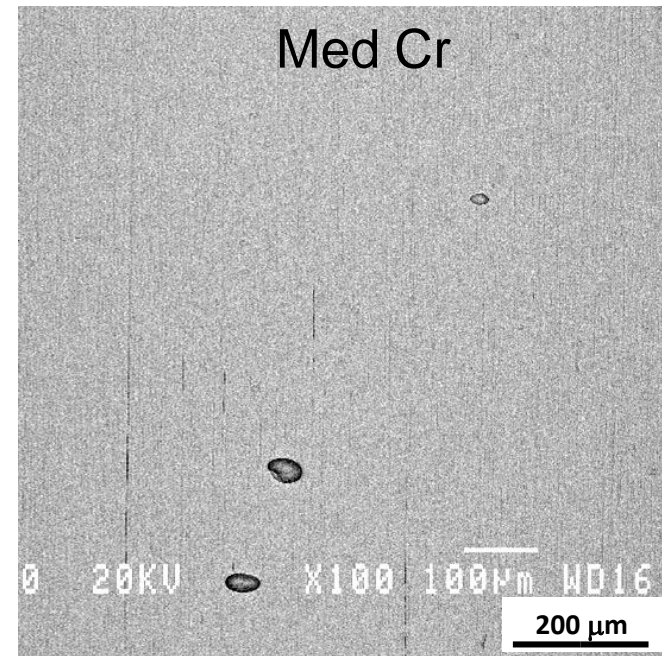
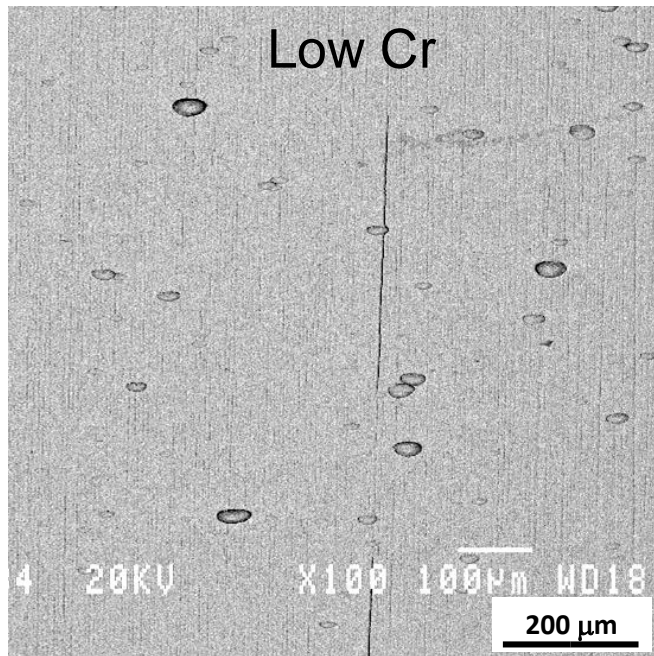
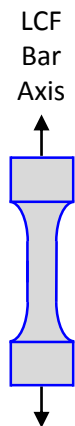
¹ Analyzed composition, nominal given as Ni-28Cr-0.15Y)

* Thickness measured on pins after 16N-200% shot peen and 8 hr low PO₂ anneal

** Composition measured by EDS



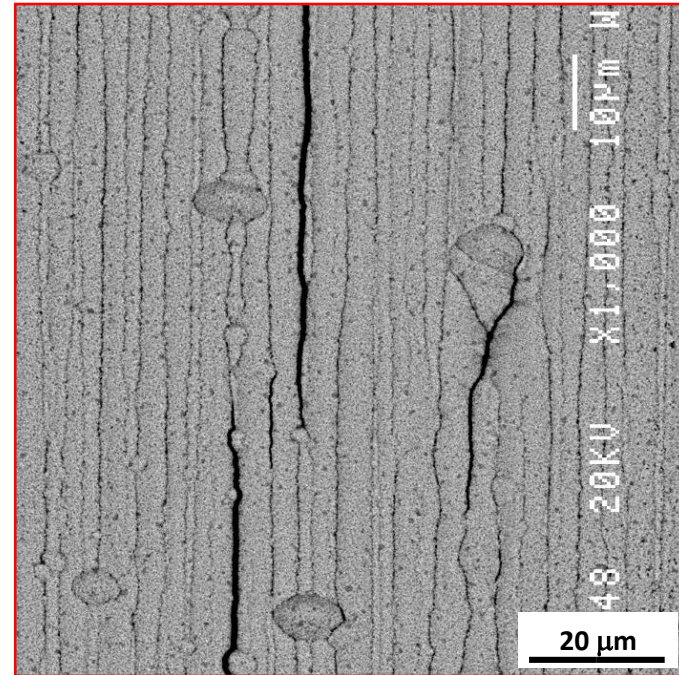
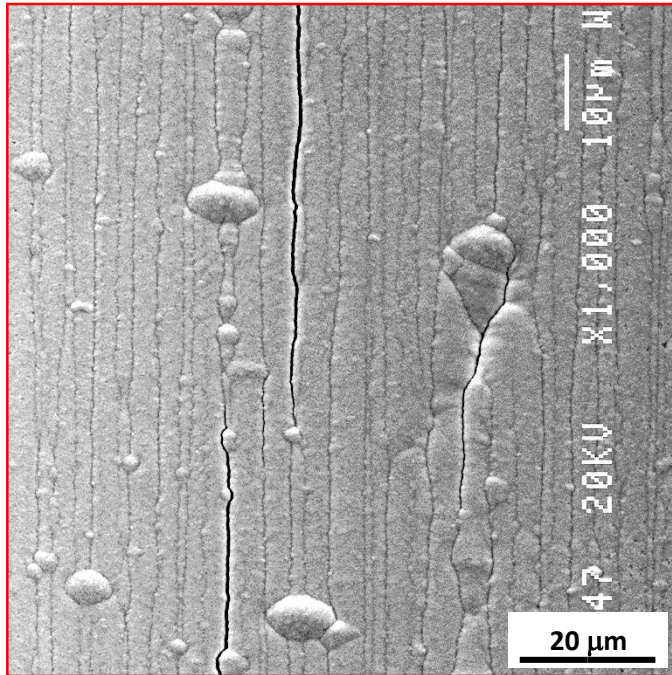
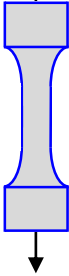
Coatings applied at SwRI, San Antonio, TX using plasma enhanced magnetron sputtering (PEMS)



“Spits” (molten droplets)
Longitudinal defects (vertical in
image)

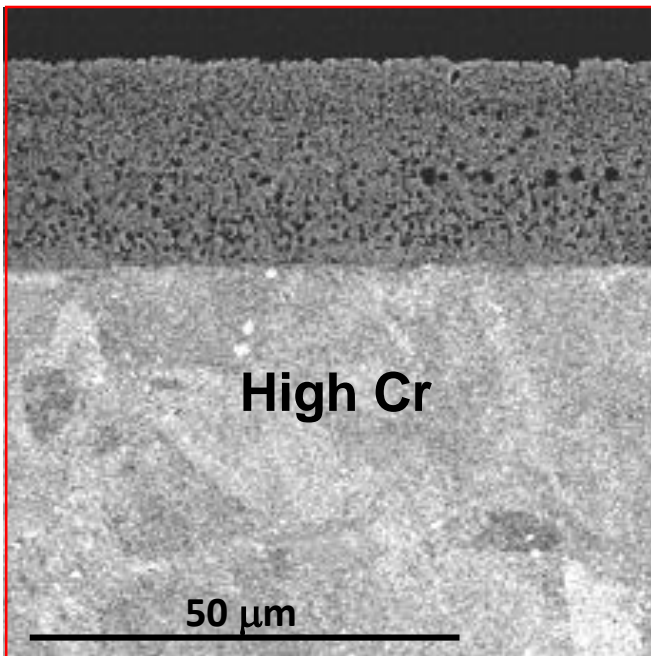
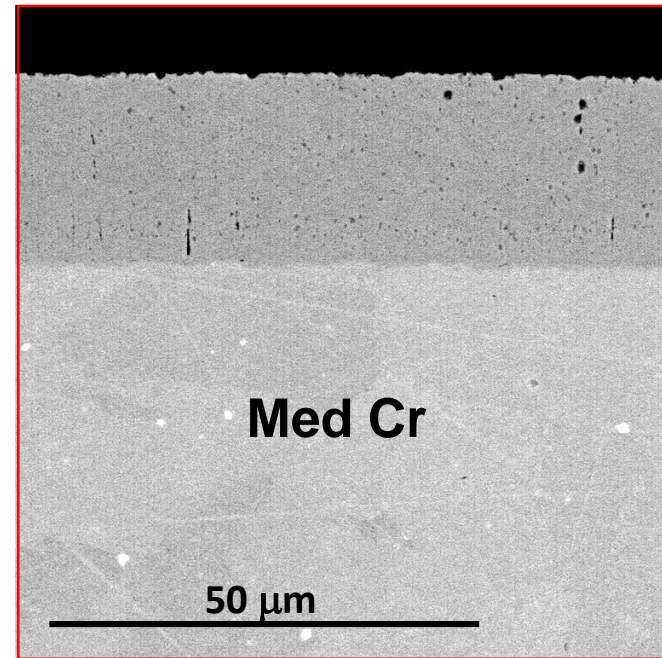
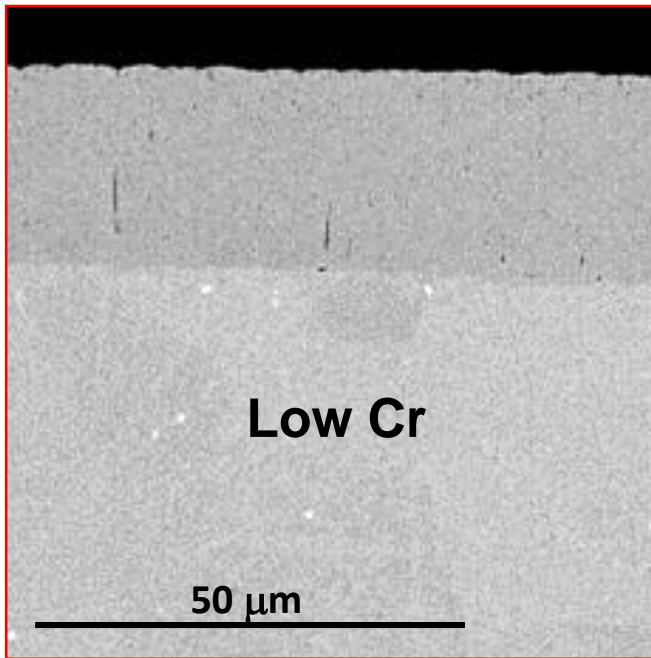
Low Cr

LCF
Bar
Axis



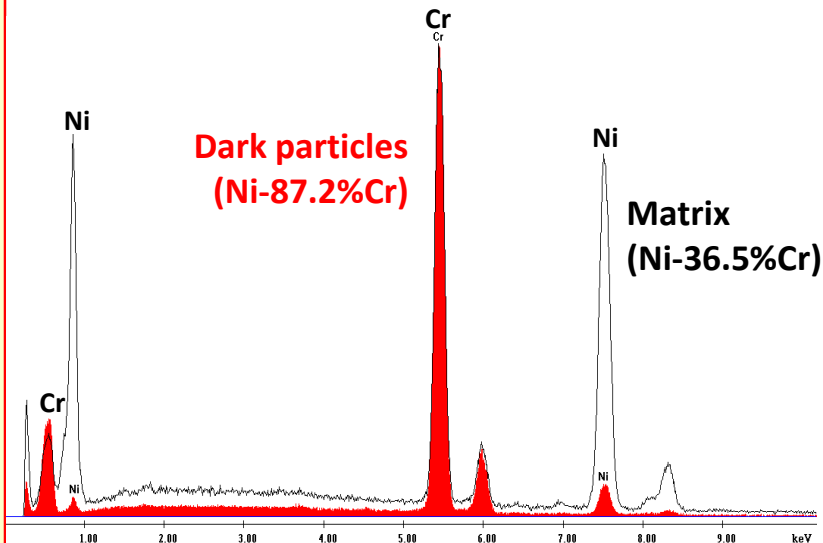
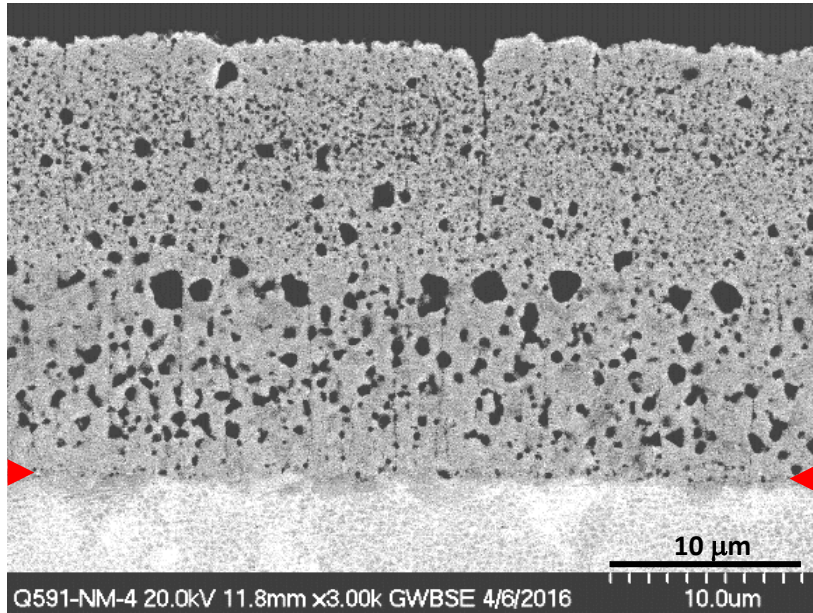
Spits on surface

Coating texture follows longitudinal polishing marks on surface, creates longitudinal “cracks” or gaps.

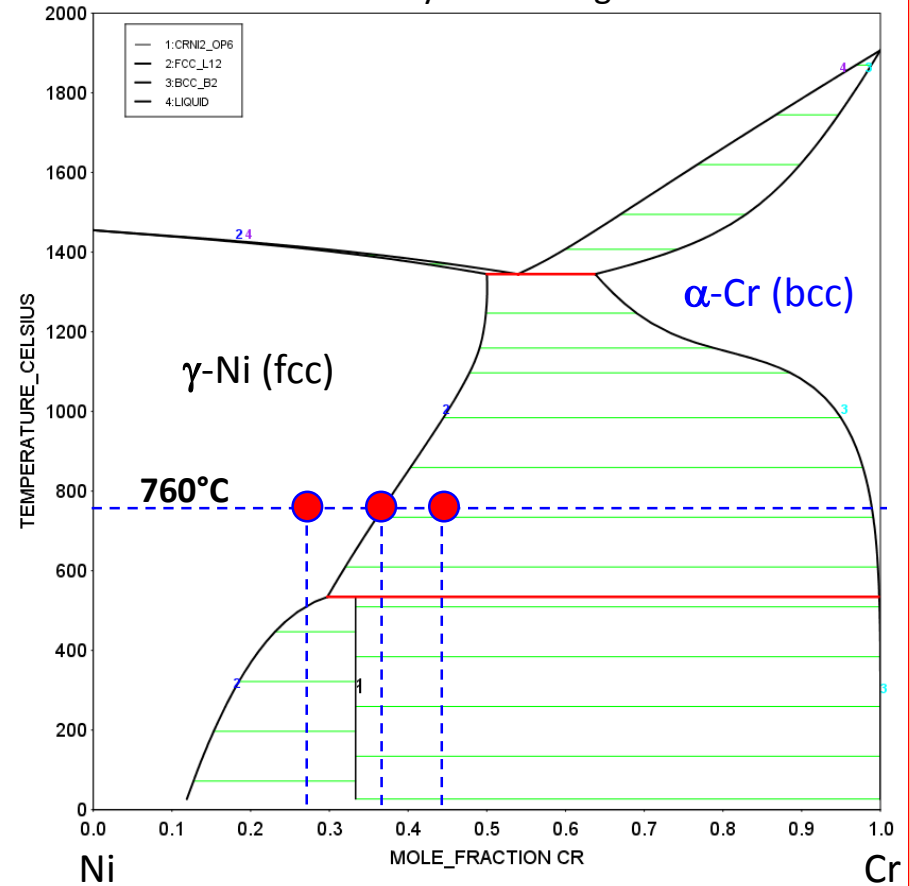


Dense, good interface, indication of columnar structure, 2nd phase in High Cr

High Cr

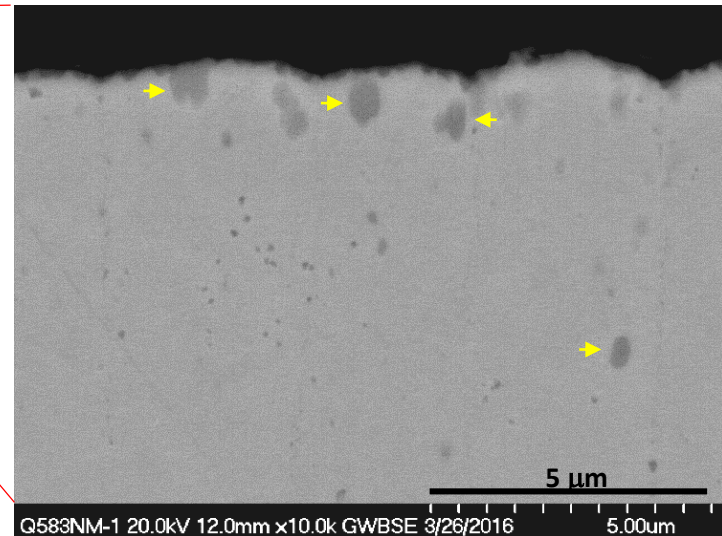
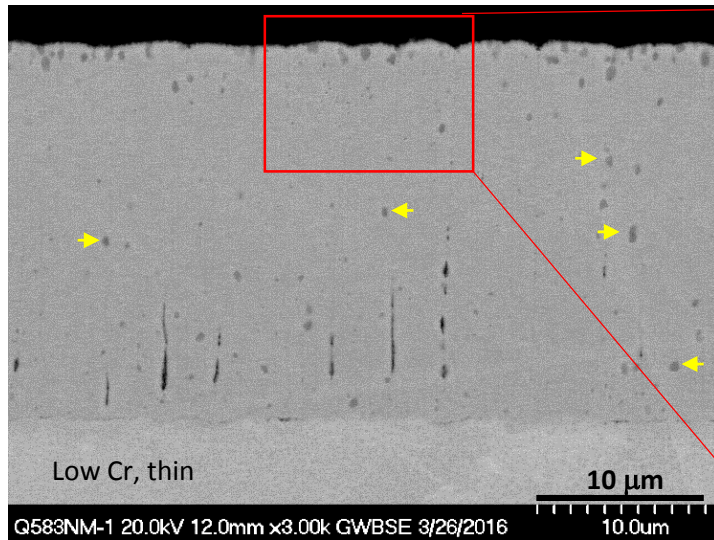


Ni-Cr Binary Phase Diagram

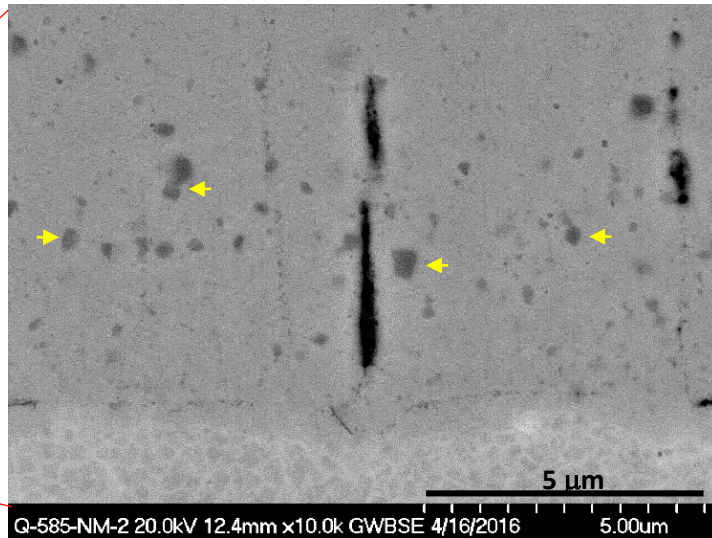
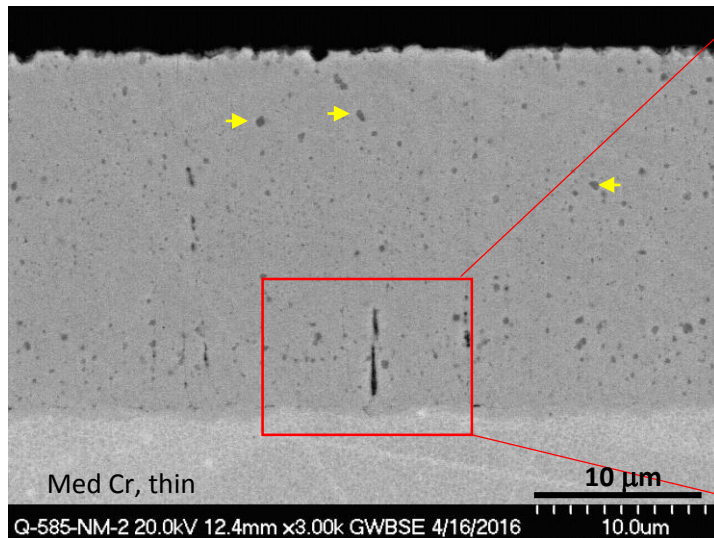


Dark, 2nd phase is α-Cr (high 90's %Cr)

Low Cr

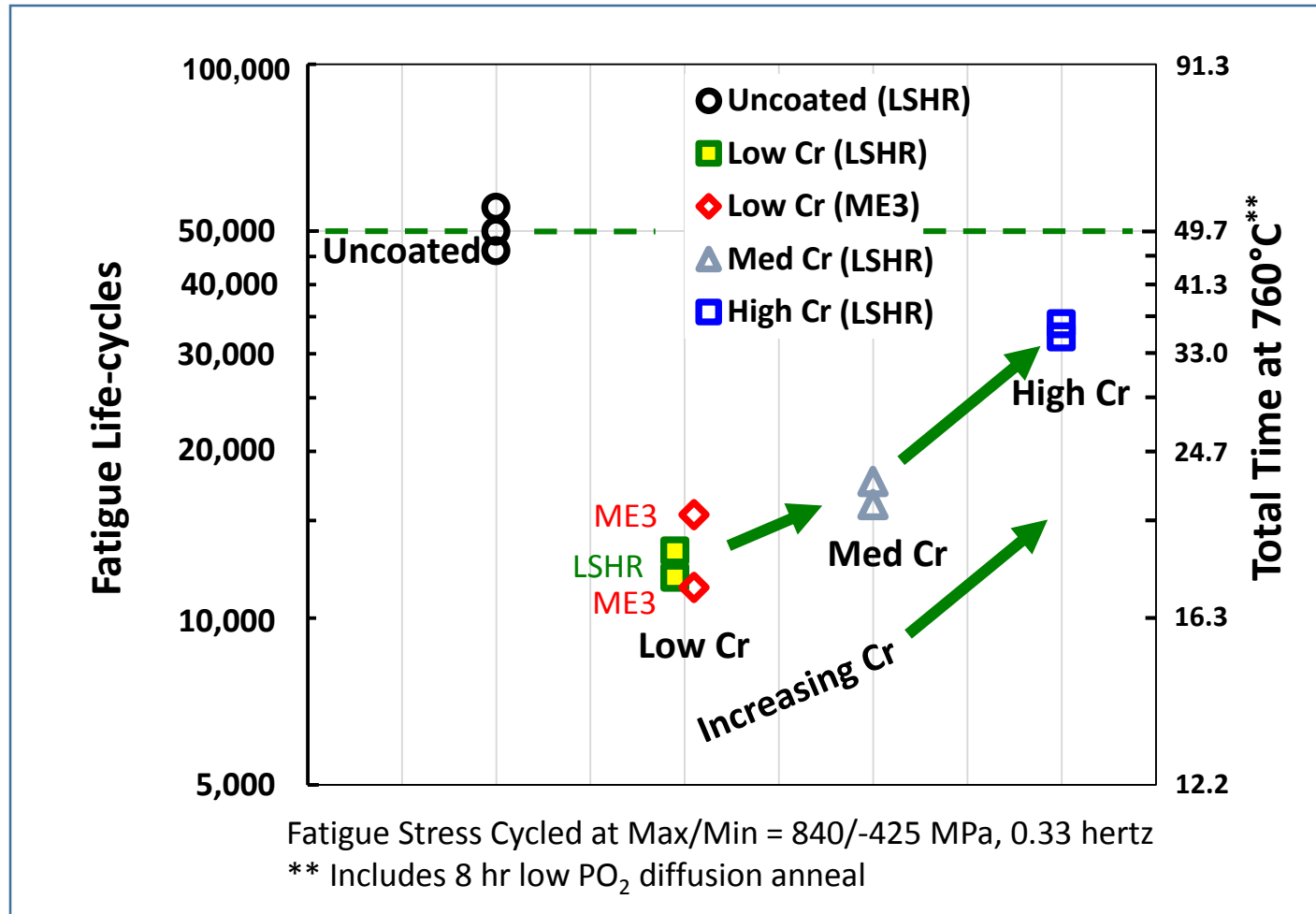


Med Cr



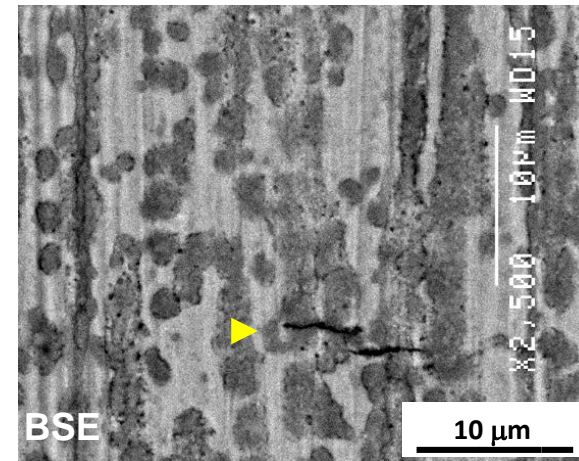
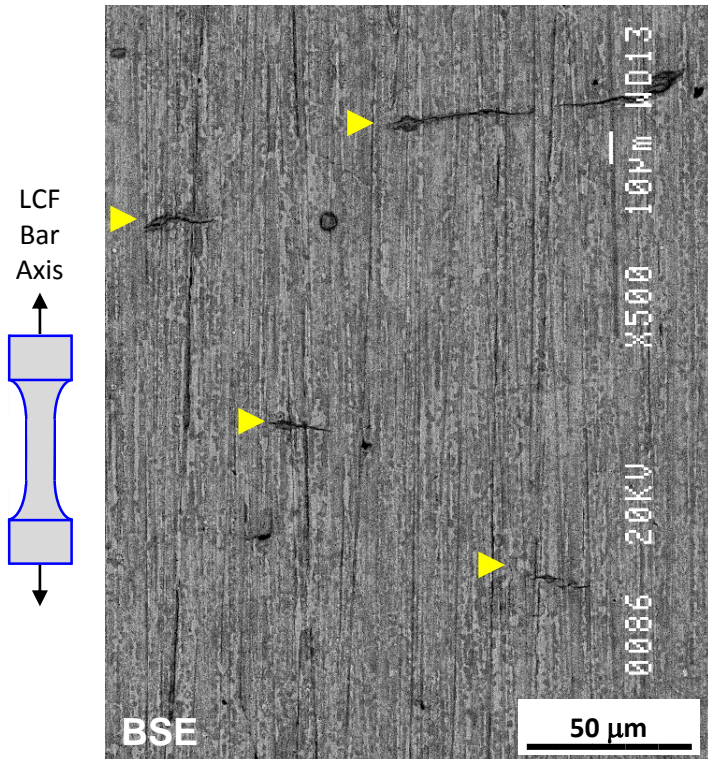
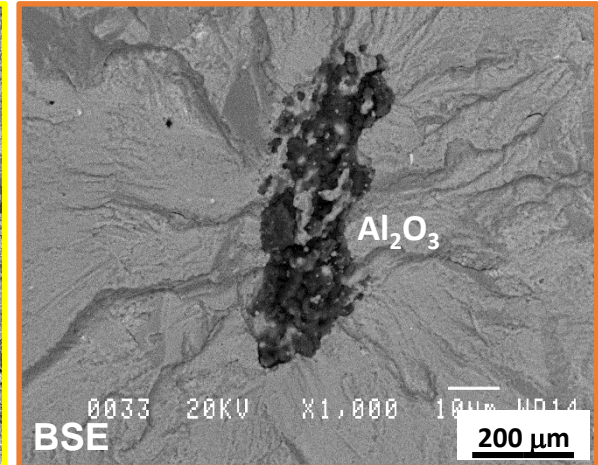
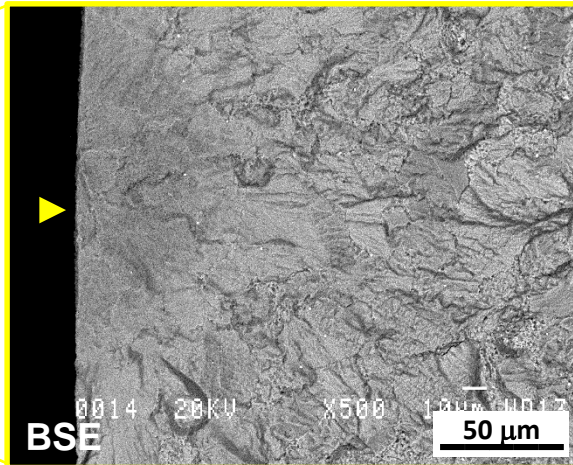
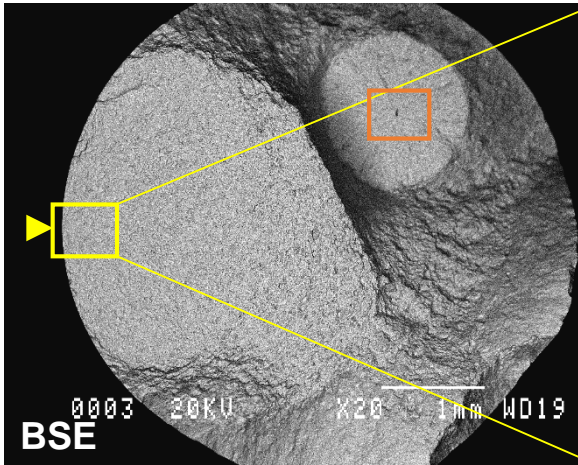
Some α -Cr in the lower Cr coatings

Fatigue Life (No Shot Peening, No OX, No HC)



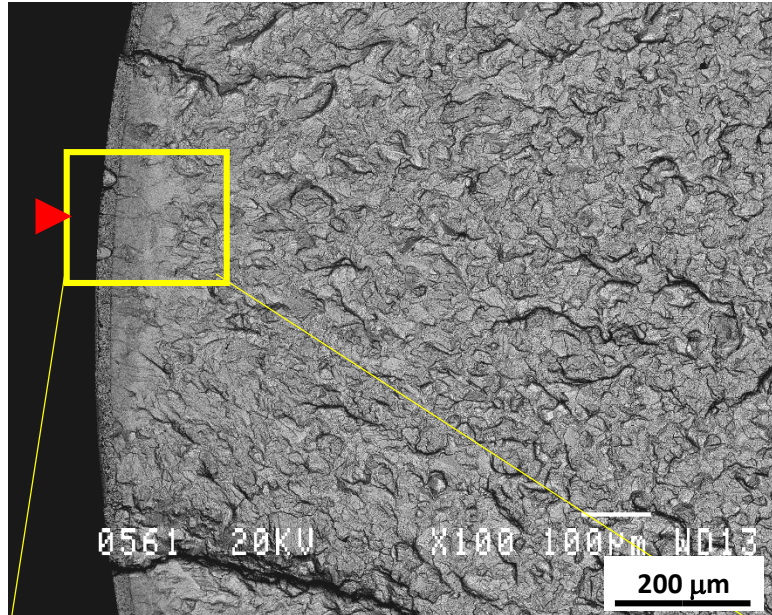
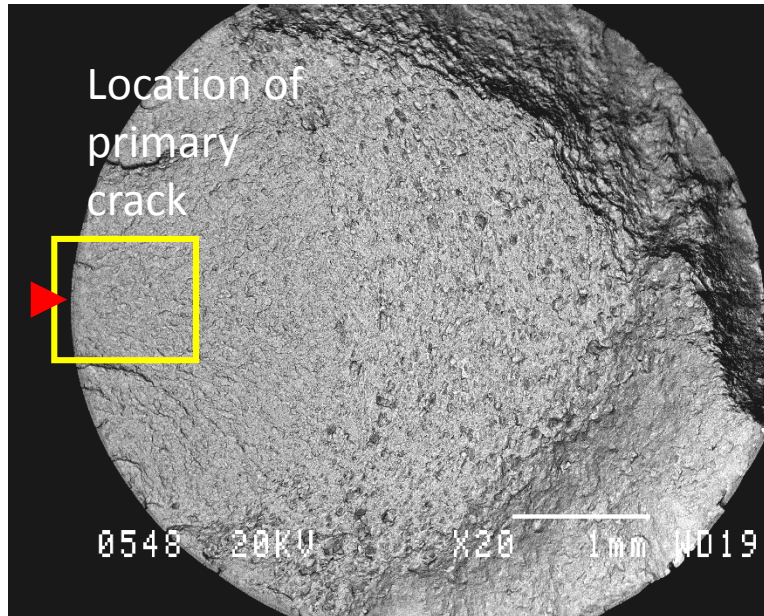
Fatigue life increases with Cr content of coating, High Cr coating attained ~70 % that of uncoated bars.

Fracture surface of uncoated sample

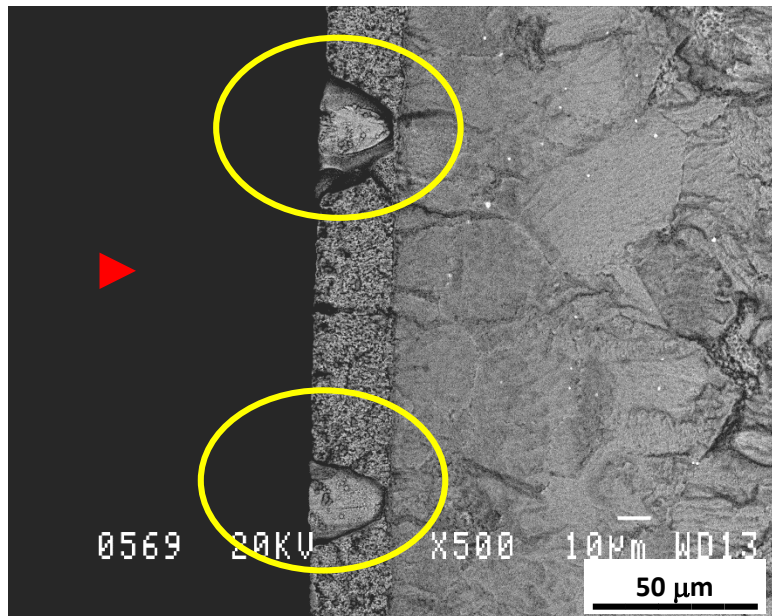


- Only very small, scattered transgranular cracks initiated on the surface
- Non-metallic inclusions sometimes initiated secondary internal cracks

Fracture surface of Low Cr-coated sample

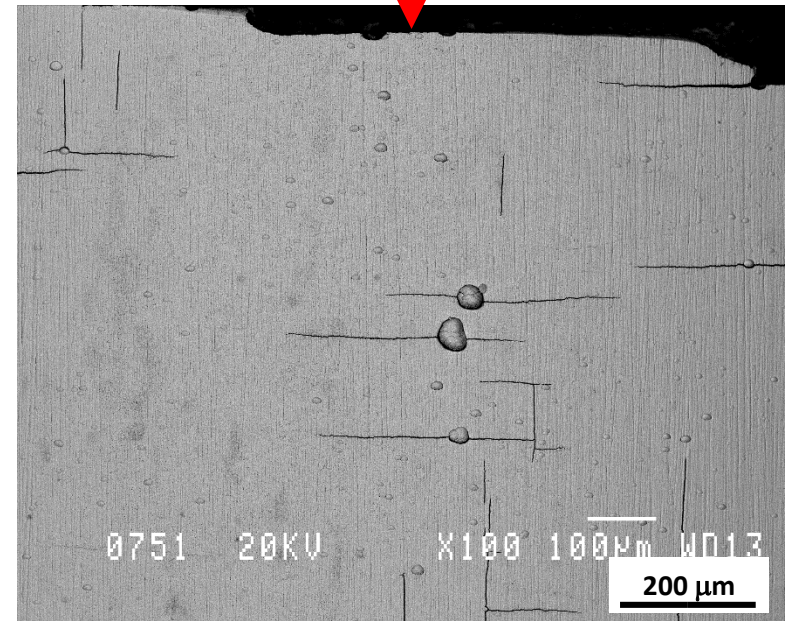
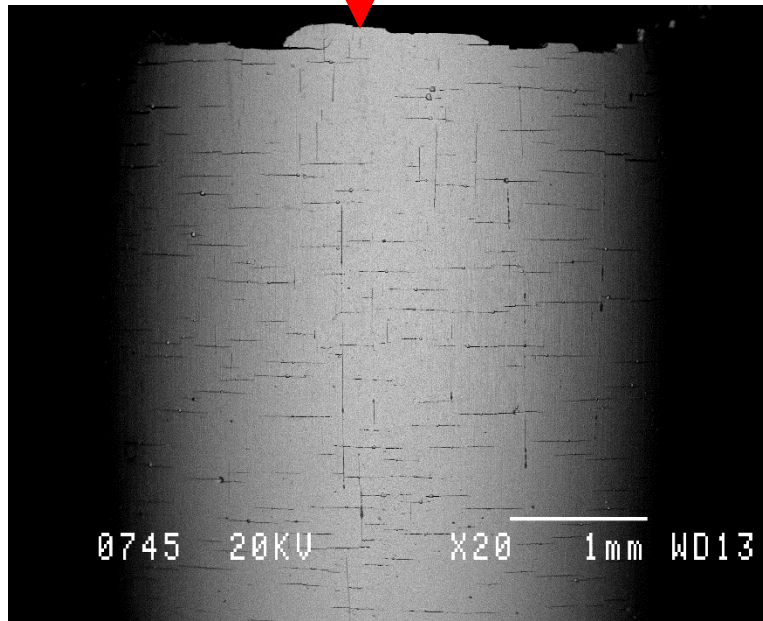
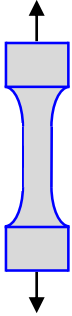


Fractography indicates primary crack causing failure initiated at surface spits

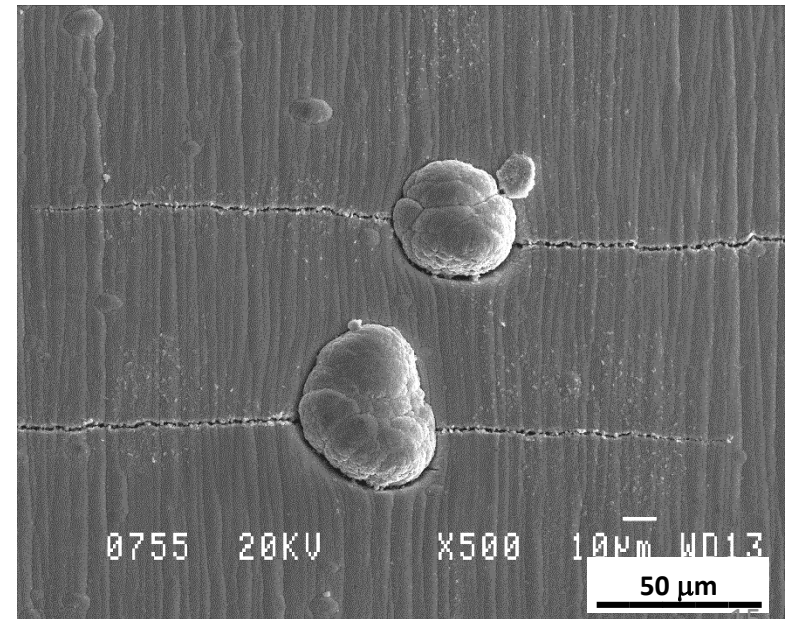


Side view of coated surface after LCF testing of Low Cr-coated sample

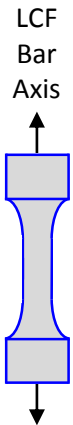
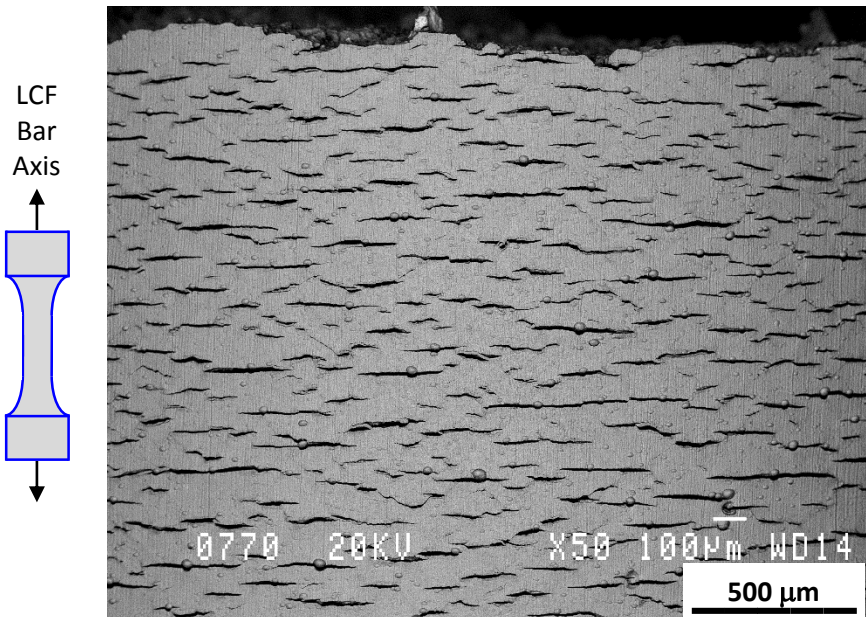
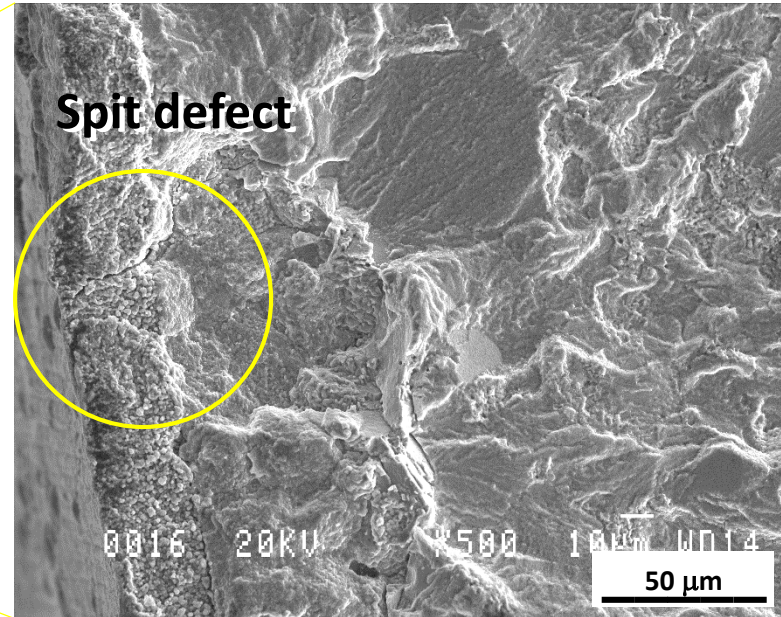
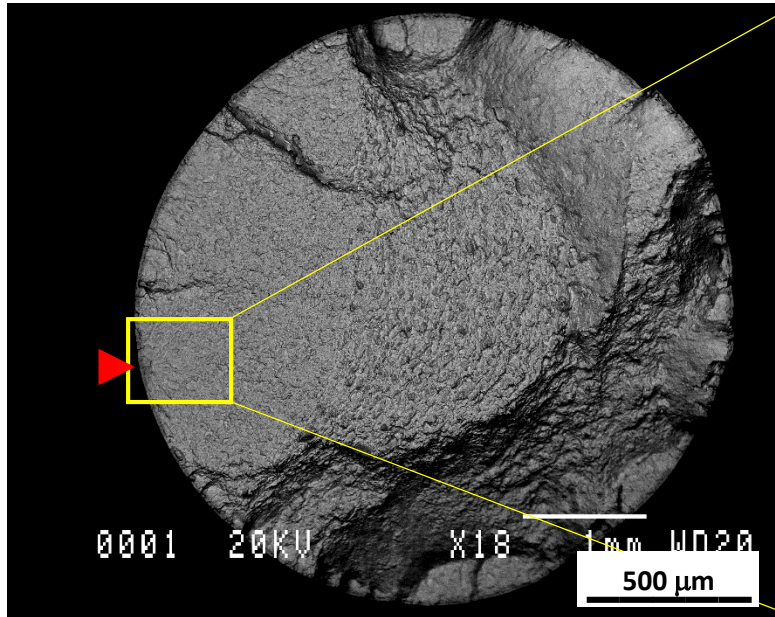
LCF
Bar
Axis



Perpendicular fatigue cracks
initiated at surface defects (spits)



Fracture surface of High Cr-coated sample having longest life

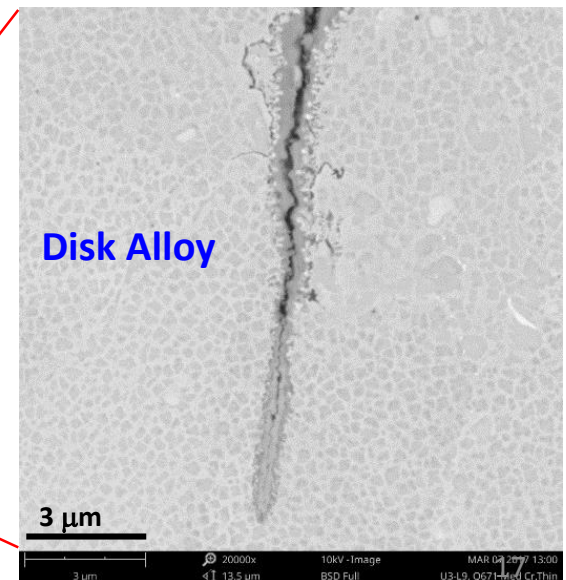
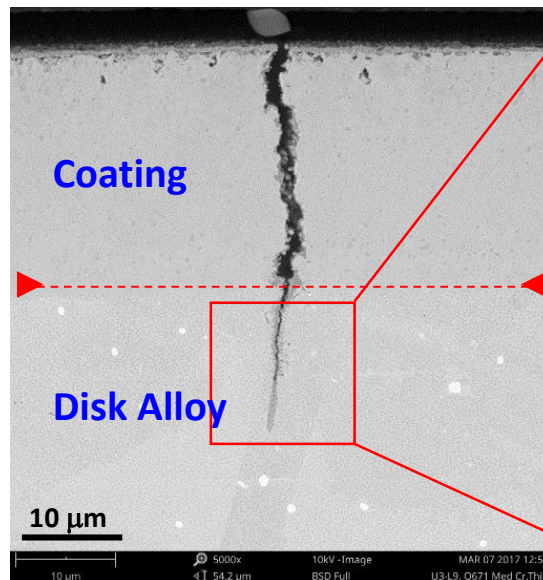
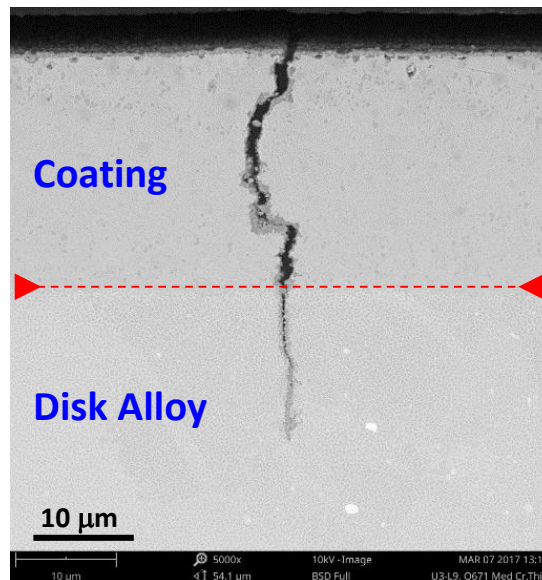
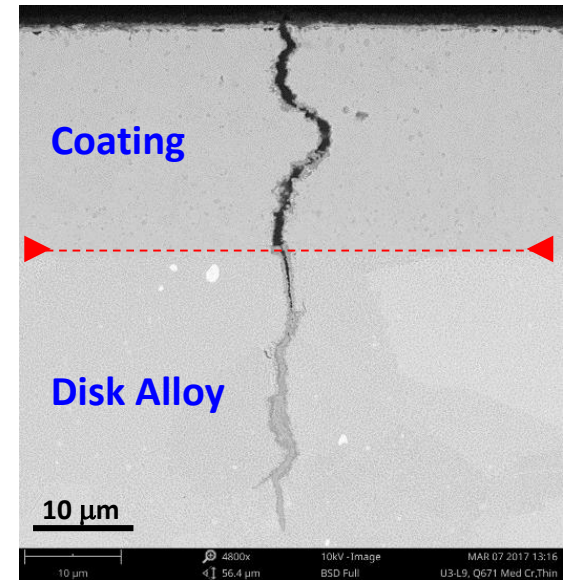
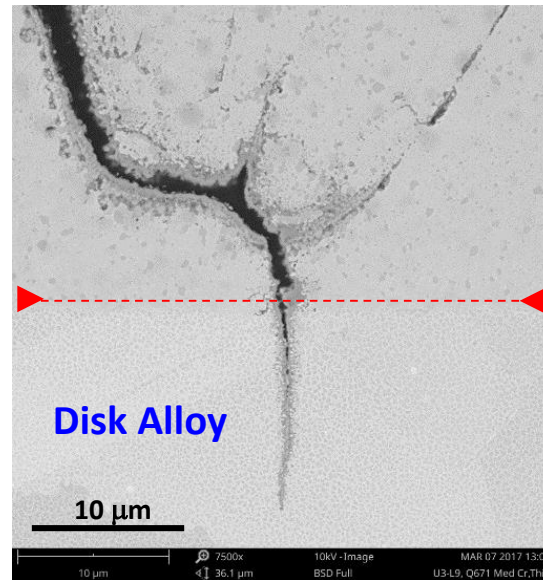
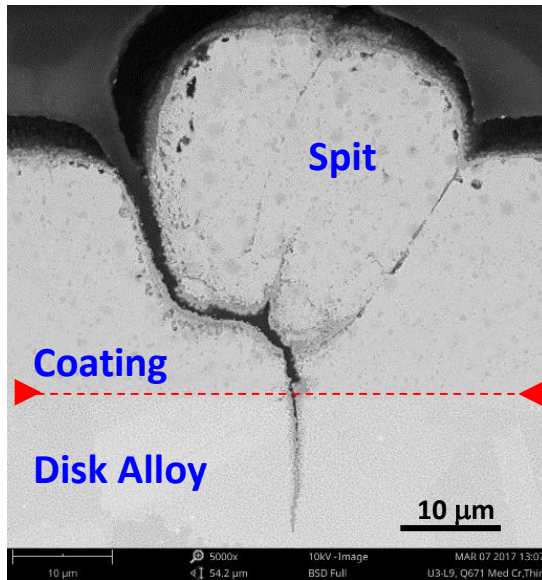


Spits usually initiated perpendicular fatigue cracks at the coating surface, though some additional coating cracks occurred elsewhere.

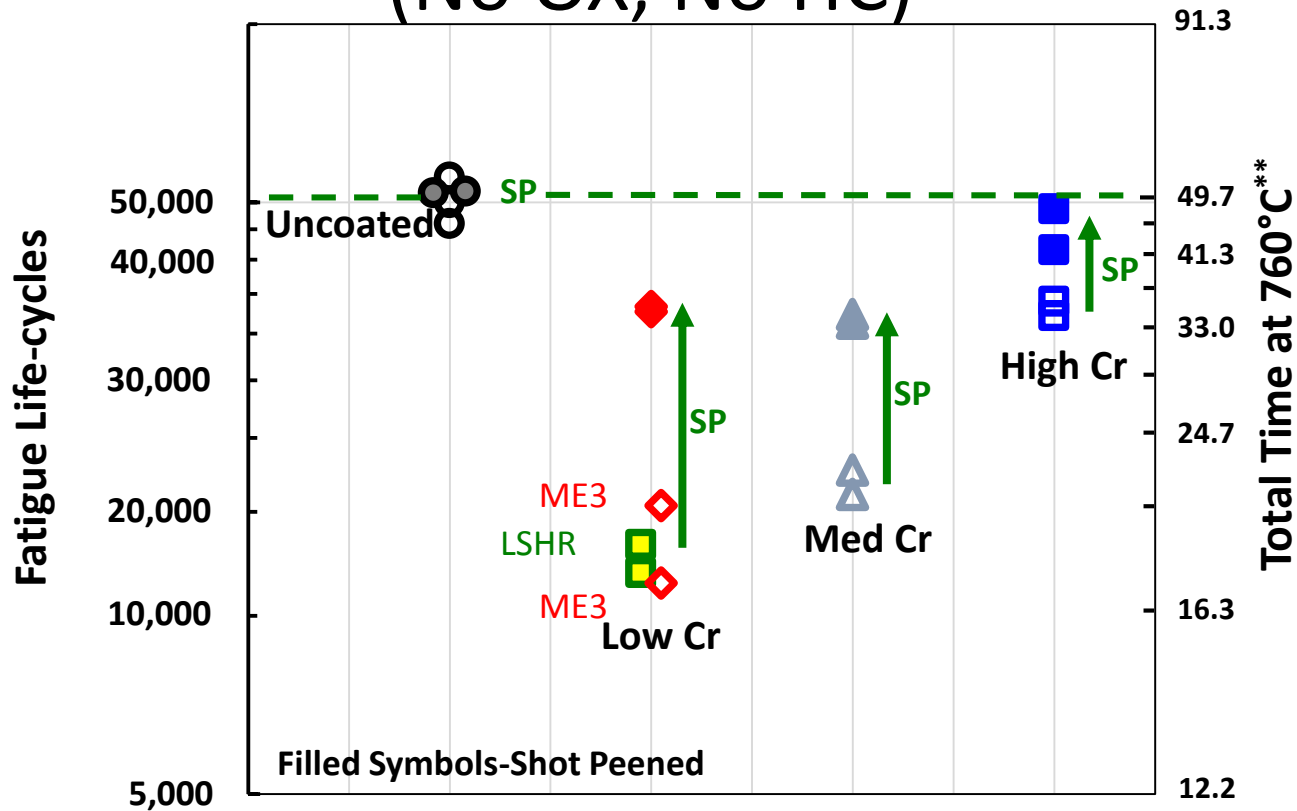
High density of cracks!

Med Cr-coated sample

Mounted longitudinally to show fatigue cracks near the site of primary crack initiation

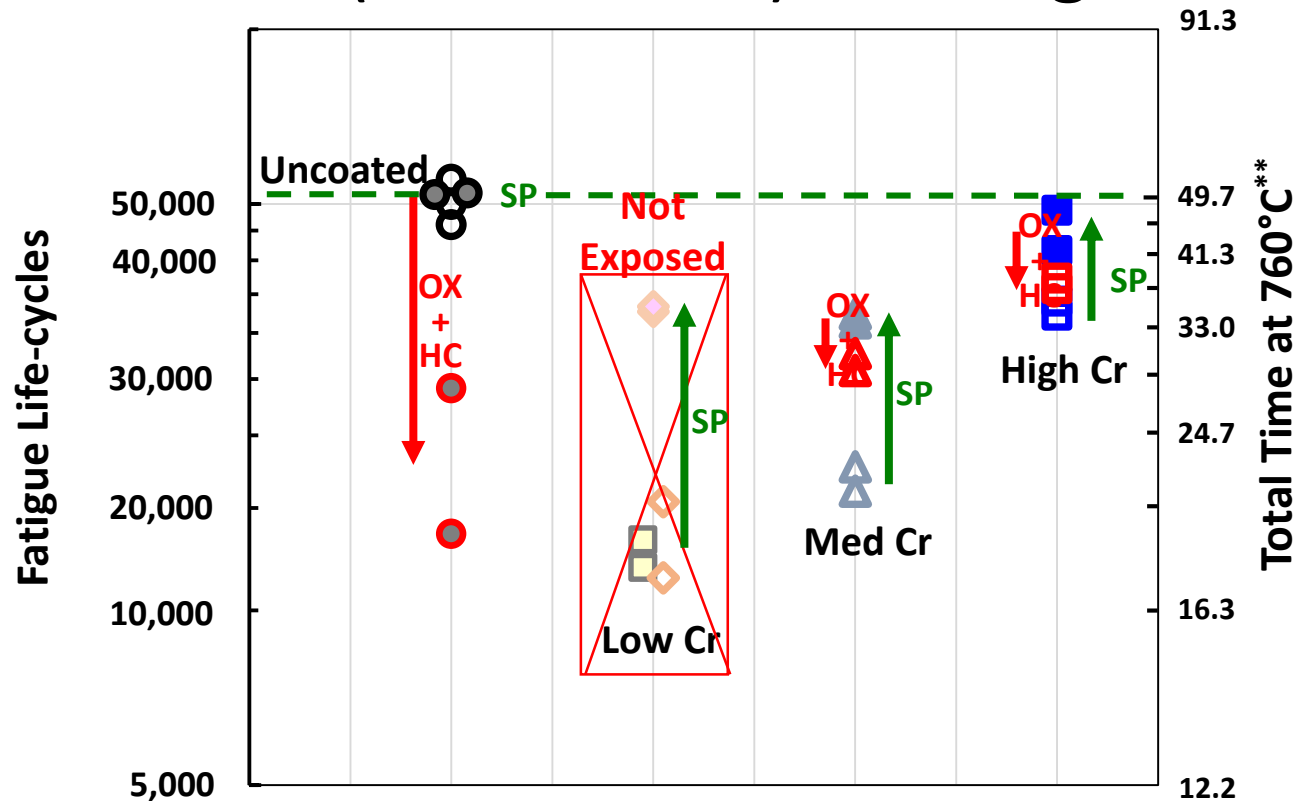


Effect of Shot Peening on Fatigue Life (No OX, No HC)



Shot Peening (SP) increases the fatigue life for all these coatings, by varied extents

Effect of Subsequent Oxidation (500hr/760°C) + Hot Corrosion (50hr/760°C) on Fatigue Life



OX + HC decreases fatigue life, but the High Cr coating gave minimal reduction in life.

Conclusions:

- The presence of NiCr-Y coatings, deposited by PEMS, can reduce the LCF life of the disk alloys without any environmental exposures.
- LCF life increased with increasing Cr content of the coating.
 - The High Cr coating (Ni-44Cr-0.15Y) consistently gave the highest LCF life of the three coatings examined, attained 80 % of uncoated life.
- Coating defects (primarily “spits”) can initiate cracks; oxidation down gaps/cracks further degraded the LCF life.
- Shot peening can increase the LCF life of coated bars for these conditions.
- OX + HC decreases LCF life of coated and uncoated bars.
 - Hot corrosion attack (pitting) was observed for uncoated specimens, yet the coatings were effective in preventing pits under the given conditions.
 - The LCF life of the High Cr coated bars after OX + HC exceeded that of uncoated bars.
- Coatings can crack more readily than the uncoated superalloy, and the cracks can propagate into the substrate to decrease the LCF life, even without environmental exposures.

Future Directions:

- Deposit coatings by HiPEMS; explore ways to reduce coating defects.
- Explore effect of coating composition. Why did Ni-44Cr do better than Ni-29Cr even without exposures?
- Examine effects of different pre- and post-coating surface treatments.
- Explore stronger, more crack-resistant, but still corrosion resistant-coatings.

Acknowledgements

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